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EFFECT OF EXPOSURE AND LOGGING ON RUNOFF AND EROSION

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ABSTRACT

High-intensity rainfall was applied artificially to plots on eight steep, forested areas in the Payette National Forest in central Idaho. Logged and unlogged sites on northeast and southwest exposures were represented equally. Results show that runoff and erosion are greater on southwest than on northeast exposures, and that even after careful logging, erosion increases on southwest but not significantly on northeast exposures.

The steep, forested mountains of central Idaho are an important source of water, but little is known about the hydrologic characteristics of their soils. Information is greatly needed, because formerly inviolate areas are increasingly subject to logging, road construction, and other influences which may well alter the hydrologic regime of watersheds and their soil mantles.

The hydrologic regime is affected also by environmental features, especially the exposure of the terrain. Logging is a human activity subject to controls, but terrain exposure must be accepted as immutable. In central Idaho, as in many other regions, areas of contrasting exposure are strikingly dissimilar, even to the casual observer.

This study investigates the effects of both logging and differences in exposure on runoff and erosion under high-intensity simulated rainfall.[2]

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[2] The author thanks Richard Meeuwig, Intermountain Forest and Range Experiment Station, and his field assistants, headquartered at Logan, Utah, for performing all laboratory analyses and for help in conducting field infiltration runs.

STUDY AREA AND METHODS

The study was conducted in the Zena Creek Sale Area of the Payette National Forest in central Idaho. Tree cover is ponderosa pine and Douglas-fir; the sandy soil, derived from the granitic Idaho batholith, is generally shallow and coarse in texture.

Eight areas within the sale unit were selected, and in these, contrasting exposure and treatment were equally represented. Exposures were generally northeast and southwest, and the areas were either logged or unlogged. In logging, small groups of trees were selected for cutting; slash was lopped and scattered. Four infiltration study plots were established in each of the eight areas. Vegetal cover varied among plots, but was generally more dense on plots on north-facing slopes. Similarly, steepness of slope varied, but was greater on north-facing slopes.

All 32 plots were located not more than 500 feet from one of two logging roads, because the Rocky Mountain Infiltrometer[3] that we used was very bulky and the terrain was steep.

Simulated rainfall was applied to each plot (50.8 X 77.5 cm.) for 30 minutes at a rate of approximately 12.2 cm. per hour. Applied rainfall and runoff were measured at the end of every 5 minutes and eroded soil material was measured after 30 minutes.

METHOD OF ANALYSIS OF DATA

The data gathered in the study were subjected to analysis with the aim of answering a series of questions suggested by the theme of the study. Appropriate statistical techniques were employed, including analysis of variance, regression analysis, covariance analysis, and multiple covariance analysis.[4] Two variables used in the study required transformations. A logarithmic transformation was tested and found appropriate for the erosion data, and the percent of bare soil was transformed to arc sin $(\text{percent bare})^{\frac{1}{2}}$.

RESULTS

The questions to be answered by the study are these:

1. Is the amount of erosion related to the amount of runoff?

2. Is runoff related to exposure?

3. Is runoff related to logging?

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[3] Dortignac, E. J. Design and operation of Rocky Mountain Infiltrometer. Rocky Mountain Forest and Range Exp. Sta., Sta. Pap. 5, 68 pp., illus. 1951.

[4] Snedecor, George W. Statistical methods, 5th ed., 534 pp. Ames, Iowa: The Iowa State College Press. 1959.

Finding the answers to the questions required consideration of the effects of differences in intensity of applied rainfall, in steepness of terrain, and in percent of bare soil. A summary of data on all these variables averaged for each group of eight plots, is given in table 1. Specific findings on the three questions are described below.

EROSION AND RUNOFF

The amount of erosion is related to the amount of runoff, as shown by the study. The relation is expressed in the following equation:

$$\log_e E = 1.35R - 0.77 \qquad (1)$$

where E is erosion in grams and R is runoff in centimeters. The equation was derived from total erosion and total runoff from each of the 32 plots after 30 minutes of simulated rainfall. The correlation coefficient between E and R was found to be 0.83; this is statistically significant at the 1-percent level of probability. Under the conditions of the experiment, the amount of soil eroded is therefore closely related to the quantity of surface runoff.

Equation 1 was developed from the pooled field data, without regard to the fact that data were gathered from plots representing four combinations of exposure and treatment (northeast exposure, logged and unlogged; southwest exposure, logged and unlogged). A covariance analysis was used to test the possibility that separate equations for each combination would differ from equation 1. This analysis indicated that the equation is a valid representation of the relation between erosion and runoff in the study area.

Table 1.--Values[1] of variables measured in study of 32 plots.

Plot group	Applied rainfall	Surface condition: Slope	Surface condition: Bare soil	Runoff	Sediment
	Cm./30 min.	Percent	Percent	Cm./30 min.	Gr./30 min.
Southwest exposure:					
Logged	6.073 ± .117	69.4 ± 3.8	55.6 ± 1.1	3.721 ± .292	170.6 ± 46.9
Unlogged	6.284 ± .076	46.5 ± 4.8	28.2 ± 9.5	2.090 ± .587	39.7 ± 24.5
Northeast exposure:					
Logged	6.060 ± .091	72.6 ± 4.5	4.5 ± 2.9	.536 ± .117	9.6 ± 8.0
Unlogged	5.982 ± .107	73.9 ± 2.5	.9 ± 0.6	.861 ± .196	2.9 ± 1.33

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[1] Values are averaged with respective standard errors for each group of eight plots representing a specific combination of exposure and treatment.

RELATION OF RUNOFF AND EROSION TO EXPOSURE AND LOGGING

Runoff is related to exposure, as shown by a covariance analysis of data on runoff and applied rainfall. The intensity of the artificial rainfall applied to the plots varied slightly, due to performance of the equipment; the average measured intensity was 0.399 inch or 1.01 cm. per 5 minutes, with a standard deviation of 0.037 inch or 0.09 cm. To minimize any error attributable to variations in rainfall intensity, an equation was developed for each plot:

$$R_t = a + bP_t T(T+1)^{-1} \qquad (2)$$

where R_t is runoff in centimeters during a 5-minute period, and P_t is applied rainfall at time T minutes from the beginning of rainfall application. (The minimum value of T is 5 minutes, and the maximum value is 30 minutes.) Analysis of the resulting 32 equations showed that plots having northeast and southwest exposures have different runoff patterns. The regression coefficients of the equations characterizing runoff from the two exposures differed at the 1-percent level of probability:

$$\text{NE exposure: } R_n = 0.25X - 0.11 \qquad (3)$$

$$\text{SW exposure: } R_s = 1.17X - 0.63 \qquad (4)$$

where R represents runoff in centimeters during a 5-minute interval, and X represents the product of the rainfall and time variables shown in equation 2; it is limited in this study to values between 0.61 and 1.25.

At an average rainfall intensity of 0.399 inch or 1.01 cm. per 5 minutes, runoff from plots having southwest exposure exceeded that of plots having northeast exposure by a substantial amount. Average values for runoff in centimeters are as follows:

Exposure	Time (minutes)	
	0-5	25-30
Southwest	0.36	0.52
Northeast	0.10	0.14

More runoff occurred from southwest-facing plots despite the fact that they were, on the average, less steep than the northeast-facing plots (57.9 percent slope compared to 73.2 percent slope--see table 1, average for logged and unlogged plots).

Southwest-facing plots were considerably more bare than northeast-facing plots (average of 41.9 percent bare ground compared to 2.7 percent). To test the importance of this fact, we made a covariance analysis of runoff data for the two exposures in relation to the percent of bare soil on each plot. The result indicated that runoff is directly related to the amount of bare soil: that is, if northeast and southwest exposures were equally bare, they could be expected to show equal amounts of runoff, but this situation seldom if ever occurs.

Runoff is related to logging, but when considered with respect to degree of slope and amount of bare soil, the relation is valid only for plots having southwest exposure. Because runoff characteristics were found to differ according to plot exposure, plot groups of northeast and southwest exposure were analyzed separately to determine the effects of logging.

Southwest exposures.--Before the covariance analysis was made, adjustments were made as before for variations in rainfall intensity, using equation (2). The analysis showed that logged plots yielded more runoff than unlogged plots did, at the 1-percent level of probability. The equations are as follows:

$$\text{Logged: } R_l = 1.17X - 0.50 \qquad (5)$$

$$\text{Unlogged: } R_{ul} = 1.17X - 0.77 \qquad (6)$$

where R and X are as defined earlier. Inspection of these equations reveals that runoff from logged plots exceeds that from unlogged plots by 0.27 cm. (per 5-minute period). However, the logged plots were both steeper (69.4 percent slope compared to 46.5 percent) and more bare (55.6 percent bare ground compared to 28.2 percent) than the unlogged plots. Adjustments were made to compensate for these differences; the covariance analysis indicated that logged plots still yielded larger quantities of runoff than did unlogged plots.

Northeast exposures.--A similar series of analyses was performed for plots having northeast exposure. After adjustment for rainfall intensity only, data indicated that unlogged plots yielded more runoff than logged plots; however, after further adjustment for differences in slope and bare ground, the data indicated that logged and unlogged plots of northeast exposure can be expected to yield equal amounts of runoff.

RELATION OF EROSION TO EXPOSURE AND LOGGING

The preceding analyses indicate that erosion is related to runoff; that plots with southwest exposure yield more runoff than those with northeast exposure; and that on southwest-facing slopes logged plots yield greater runoff than unlogged plots. These conclusions suggest that the erosion pattern is similar to the runoff pattern, and analyses bear this out.

Analysis of variance shows that plots with southwest exposure yield more sediment than those with northeast exposure (1-percent level of probability), and that logging is related to increased erosion only on southwest-facing slopes (5-percent level of probability). Adjustment (by multiple covariance analysis) for plot differences in amount of bare soil and degree of slope did not cause any change in the conclusion.

DISCUSSION

The results of the study have implications for practical management of the land and for further research. Significant relations are indicated between erosion and runoff, between erosion and exposure and logging, and between erosion and soil characteristics.

1. Erosion and runoff.--Analyses show that erosion can be expressed as a logarithmic function of runoff, as in equation

$$\log_e E = 1.35R - 0.77$$

The equation is highly significant for land management, since a slight increase in 30-minute runoff, as from 1 cm. to 2 cm., results in almost a fourfold increase in erosion, from 1.8 grams to 6.9 grams. Thus, any land management practice which increases runoff may bring about a very large increase in erosion. The land manager must bear this relation in mind when weighing the consequences of proposed use of land.

2. Erosion as related to exposure and logging.--Analyses show that in the study area erosion is related to terrain exposure. Under the impact of intense rainfall, erosion from plots having southwest exposures greatly exceeds that from plots having northeast exposures. The effect of logging, even when this is carefully done, as it was in the study area, is to magnify the difference severalfold. The number of trees on southwest-facing plots is small, and lopping and scattering logging debris does not overcome the effects of the logging activities; on northeast-facing slopes, tree density is much greater, and the removal of a few selected stems, with subsequent scattering of logging debris, appears to compensate fully for possible land damage from logging activities.

The pronounced effect of even light logging on erosion from southwest-facing plots emphasizes the problem confronting the forest manager. Merchantable timber is found on south slopes, yet logging activity may result in a phenomenal increase in erosion.

3. Erosion and soils.--It has been shown here that in an experimental logging area in the mountainous region of central Idaho, the erosion-inducing effect of high-intensity rainfall varies, depending on exposure; it is greater on southwest-facing slopes than on northeast-facing slopes. We may hypothesize that soil differences associated with slope and topography are a major contributing element.

Differences between the climatic environments of north and south exposures are accentuated in mountainous areas, and ultimately result in soils whose characteristics are noticeably divergent. Although surface characteristics (such as degree of slope or amount of bare soil) may at times strongly influence erosion, the fundamental reason for differences in rates of erosion may lie in the nature of the soil.

In an analysis of variance, a partitioning of the soil erosion sums of squares for the four different combinations of exposure and treatment shows that a certain portion of these sums can be explained by degree of slope, and that this explained portion can be increased if both degree of slope and amount of bare soil are considered jointly.

The figures are as follows:

Exposure and treatment	Sums of squares accounted for by	
	Slope alone	Slope and bare soil
	(Percent)	
Northeast		
Logged	19	41
Unlogged	15	65
Southwest		
Logged	4	90*
Unlogged	89*	97**

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*Significant at 5-percent level of probability.

**Significant at 1-percent level of probability.

This tabulation shows that slope gradient in conjunction with the amount of bare soil accounts for a highly significant amount of the total variation in soil erosion on southwest-facing plots. On northeast-facing plots the proportion is not statistically significant, but may be of practical importance. It may well be that certain soil characteristics are strongly correlated with slope and amount of bare soil, and that these characteristics may ultimately be defined in such a manner as to explain the variation in erosion. Further research along these lines is indicated.

FOREST SERVICE CREED

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